Remarks to the DOE Nuclear Criticality Safety Program

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The best place to look to find out how the Board feels about the importance of protection against accidental criticality is within the Recommendations that the Board has issued to the Secretary of Energy.

Among the early actions of the Board was a response to the observed moves within the Department of Energy to close down operation of the Critical Assembly Facility at TA-18, at the Los Alamos National Laboratory, to save the relatively small amount of money that operation of that facility cost each year. At one time the Department of Energy and its predecessor agencies had simultaneously conducted critical experiments at about a dozen locations in this country. The researchers at those facilities provided a ready and constant and highly valuable supply of personnel well informed through personal experience of the factors that could contribute to accidental criticality and the measures needed to avoid it. These personnel were constantly drawn on not only at their sites but throughout the complex as advisors on criticality and as monitors of the safety of the Agency's programs. At several defense nuclear facilities the criticality experts were central to design of operations.

Some of the defense nuclear facilities where critical experiments were conducted partly for such purposes were Oak Ridge, Hanford, Rocky Flats, Savannah River, Los Alamos, and Livermore. In 1993 except for some intermittent operations at Sandia only the experimental operations at the TA-18 Facility at Los Alamos remained of all of those once thriving programs. The Board looked upon both the still existent experimental and educational activities at TA-18 as crucial to maintenance of protection against the possibility of future criticality accidents in the DOE complex. Accordingly, the Board issued its Recommendation 93-2 to forestall that closure.

I shall quote some of that Recommendation. The Board observed that the art and science of nuclear criticality control have three principal ingredients. The first is familiarity with factors that contribute to achieving nuclear criticality, and the physical behavior of systems at and near criticality. This familiarity is developed in individuals only through working with critical systems. It cannot be imparted solely through learning theory and using computer codes. The second is theoretical understanding of neutron multiplication processes in critical and subcritical systems, leading to predictability of the critical state of a system by methods that use theory benchmarked against good and well characterized critical experiments. The third is thorough familiarity of nuclear criticality engineers with the first two factors, obtained through a sound program of training that indoctrinates them in the experimental and theoretical aspects. Let me note that this is the same as the ordinary wisdom that learning to be a doctor requires work with sick people.

The Board went on to say that it is also important to conduct further neutron chain-reacting critical experiments targeted at the major sources of discrepancy between the theory and the experiments, as well as careful analysis of the experiments. It was also noted that there is no guarantee that the physical circumstances of handling and storage of fissionable material in the future will always be found in the realm of benchmarked theory. Experiments of new kinds may be needed to clarify issues so raised. This point is especially important under circumstances that will exist for a number of years to come, with increasing amounts of fissionable material to be stored in a variety of chemical and physical forms.

The Board recommended as follows:

1. The Department of Energy should retain its program of general purpose critical experiments.

2. This program should normally be directed along lines satisfying the objectives of improving the information base underlying prediction of criticality, and serving in education of the community of criticality engineers.
3. The results and resources of the criticality program should be used in ongoing departmental programs where nuclear criticality would be an important concern.

That was a minimal set of recommendations, which nevertheless embodied the heart of the concept that the Board espoused then and espouses now. There should be a healthy program at a chosen DOE facility. It should include some experiments directed at problems in real world criticality control. There should be an associated program of instruction in which criticality engineers could experience phenomena near, at and above criticality first hand. The Board indicated no preferred location for such a program, but since only a single facility remained in continuous operation, that was not necessary.

The Secretary of Energy accepted the Recommendation and provided an implementation plan in response to it that met the immediate objective sought by the Board. Shutdown of the operations at T-18 was averted, and the formal instruction in criticality control at that facility was strengthened and was made a continuing service.

However, by 1997 the Board perceived that problems still remained. It was not evident that the experimental program at TA-18 was as effective as desired in helping to solve the everyday problems of criticality control in the Department's programs. It appeared that the instruction given in the TA-18 course might be too perfunctory, not providing criticality engineers as much of a real feeling for the phenomena as is needed. There was a perceived need for DOE's facilities to do more sharing of answers to common criticality problems. There was a need to restructure the relationship between criticality control and the line function of operations at some sites. Finally, each year the program suffered financially because it had no budget of its own. Meeting each annual budget required soliciting contributions from several DOE Offices, several of which were reluctant to do their part. To solve all these problems at once, the Board issued its Recommendation 97-2, which addressed them all.

Again the Secretary of Energy accepted the Recommendation and provided an implementation plan to which the Board agreed. A number of the presentations being made at this workshop reflect response to that recommendation. I believe that some of the problems addressed by Recommendation 97-2 continue to exist. For instance, there still does not seem to be a concerted attempt to share among active DOE sites the results of calculations made for criticality purposes, though some of the problems encountered at different sites are essentially identical.

The Board continues to support maintaining the DOE's program of research and instruction in prevention of criticality as absolutely essential. A criticality accident can threaten a whole nuclear industry, as has been the case in Japan. In the United States continued nuclear safety is also important to ensuring the continued health of the defense programs. For this reason the Board has kept a watchful eye on the budgetary status of the DOE's program, and on actions that may move the activities at TA-18 in Los Alamos to another location either at Los Alamos or at another DOE site. Without wishing to insert itself unduly into DOE's decision-making process here or in other places, The Board will not look favorably on any change that weakens the services presently provided at TA-18. The Board regards criticality research and instruction to be essential components of DOE's defense programs. In my view, moving these activities to another DOE site would threaten severely the effectiveness of these programs.

Now I'd like to turn to what at first glance appears to be a somewhat different subject, which is a lessons learned from the criticality accidents that have occurred up to the present. The first compilation of accounts of criticality accidents along with discussion of their causes and lessons to be derived from them was done in the mid 1960s by Theos Thompson, who was the principal designer of the Omega West research reactor at Los Alamos, who was responsible for much of the development of safety tradition and practices in the nuclear power industry, and who was killed in a most unfortunate plane crash while serving on the Atomic Energy Commission. A revised and updated account of accidents was compiled by Bill Stratton at Los Alamos, with further revision in time by Dave Smith, also of Los Alamos. That has now in turn been updated by a document prepared by a joint US-Russian group of authors. The addition of accounts of accidents that occurred in the Soviet Union has helped the record to be much more instructive. I suspect that accidents have occurred in other countries such as China, and it would be highly useful to learn about those, also. I have read the new document with much interest, and I drew a number of conclusions that I'd like to share with the audience here. There are a number of connections to the motivations for the Defense Board's actions.

It has been noted in the past that there is added hazards when operations must take place with solutions of fissionable material, either plutonium or U-235. The recent accident at Tokai-Mura was an unwelcome addition to a list of events in this country and in the Soviet Union that occurred when operations were undertaken with solutions and which also led to fatality of workers. Some accidents such as at the Japanese site were the result of actions by personnel who did not have an appreciation of the hazards they faced. Some accidents with fissile solutions had somewhat more subtle origins.

We all depend on three modes of control in prevention of criticality accidents: control of quantity, control of concentration, and control of geometry. In practice, all have failed in some fashion at one time or another. Limitation of the amount or the concentration of fissile material to be below some "safe" level, can both be weak reeds. They are of course based on good science. But both become strong enough only when they are assiduously monitored and when they are not used alone but are part of a pattern of defense in depth. The two methods of control are closely related, both being procedural in nature. Sometimes in spite of precautions operations have been confounded by mistakes leading to processing of solutions containing more than the safe amount. Two examples of failure in American operations are especially noteworthy, each of which had fatal results. The first one occurred in 1958 at Los Alamos, and the second one in 1964 at Wood River Junction in Rhode Island. The former resulted from incorrect expectation as to the fissionable content of waste solution to be cleaned up. The latter was the result of incorrect identification of material to be processed, because labels fell off bottles of solution. Similar fatal accidents occurred at facilities in the Soviet Union.

Geometric control is widely regarded as more reliable, and I agree with that verdict. Its value was recognized a long time ago. I remember that the first time I visited the Y-12 area at Oak Ridge, in connection with critical experiments at Dixon Callihan's old facility, someone pointed out to me a building then being used for office space, but which had been erected during Manhattan Project days as a facility for chemical processing of highly enriched uranium. After it had been completed but before it was used, Dick Feynman had become suspicious of the sizing of some of the piping. He did some calculations and that facility never started up. Incidentally, he used pencil and paper methods for the analysis. Monte Carlo methods had not yet been developed, but I doubt that he would have used them if they had been available.

Most criticality accidents involving liquids could have been averted if vessels with safe geometrical sizes had been used. However, even geometry control is by no means an infallibly safe method under all circumstances. There have been accidental criticalities under geometry control as well. In some instances incidental connections to other equipment with unsafe geometry have led to the mishaps. Fissionable material has accumulated in oil reservoirs of vacuum pumps used to make material transfers. In the absence of a siphon break, siphon action has moved solution from a safe geometry container to one with unsafe geometry. Precipitation resulting from chemical changes notably oxidation has altered the geometrical requirements for safety against criticality, for slurries can carry a much higher density of fissionable material than a solution.

It is very interesting that there have never been any criticality accidents attributable to interaction between distinct containers of fissionable material, with the possible exception of one accident at a Russian facility where other factors came into play and interaction may have been the last straw. Another interesting point is that there do not seem to have been any accidents resulting from errors in storage practices. There have been no instances of criticality resulting from transportation, either normal transport or transportation accidents. Yet most of the complex Monte Carlo analysis for criticality protection is devoted to problems of just these kinds, particularly interaction of arrays of containers during processing or storage, and probably most declared criticality infractions involve violation of limits based on possible interaction. This observation supports the Board's stress on use of simplified analytical methods for criticality analysis. For example, I have in the past verified through benchmarking that simple two-group theory provides an excellent fit to criticality of isolated containers of solution, if reasonable values of diffusion length and slowing-down length are used. Moreover, the absence of accidents caused by interaction is in accord with the fact that interaction will in most instances contribute only a minor amount to neutron multiplication of separate containers, which is already subject to important safety factors. Where complex calculations are made using codes that submerge the physics, it is important at least to have a reality check based on simple methods. This can be provided by a simple process for analyzing criticality of isolated units, supplemented by a simple benchmarked method of bracketing the perturbation induced by interaction.

To recapitulate, criticality accidents that have occurred show that no general types of protective measures can be relied absolutely on to prevent criticality accidents. Prevention of accidents in this field requires a list of ingredients similar to those used to ensure safety from other kinds of accidents. They include understanding by operators of elements of the science of what is to be done along with recognition of hazard points and causes of hazard, clearly formulated procedures prepared with safety in mind, training in respect for the procedures and in their use, and intelligent oversight by criticality specialists such as those present here. Some other important ingredients are: do not reduce safety by submission to pressures for production; do not try to do hazardous jobs when you are tired. I have a personal story in this regard. Some years ago my group was working three shifts of critical experiments in connection with design of the Brookhaven High Flux Reactor. One might I was on the graveyard shift. After one run it was necessary to make an adjustment to the assembly, and I went back into the shielded experimental enclosure to do that. I was tired. Suddenly I realized that I was lifting manually one of the scram rods to make the adjustment easier. An identical act had caused an accident at the ZPR-1 facility at Argonne a number of years before and a similar event had been the cause of the major accident at the SL-1 facility in Idaho. Fortunately, at Brookhaven we had built into our design a defense in depth, including adherence to the stuck rod criterion, recognized as important after SL-1. So we had no excursion. But clearly our bad practice on that occasion cut into the margin of safety and I have been conscious ever since of the results that might have ensued..

In avoidance of accidental criticality, defense in depth is at least as important as it is for nuclear safety in general. Without defense in depth, there is no safety in this field.

A best component of defense in depth is design of operations that makes it natural to do things the safe way. It should be difficult to do the wrong thing. Some examples of this that I have seen are: prohibit the presence in the facility of containers with unsafe geometry; avoid the presence of big tables on which items can be laid at random, or stacked.; provide an orderly and confined laydown area for fissionable material that prevents excess accumulation of items. This is sometimes called ergonomically safe design.

Nothing, however can take the place of application of sound human intelligence. That is where actions of individuals at this meeting on criticality safety are important. You must be involved in generating assurance of criticality prevention from the initial design of operations to their actual conduct on the operating floor.

Some of what I have said may sound hortatory, but I don't mean it to be. I no longer can speak from the standpoint of a member of the Defense Nuclear Facilities Safety Board, but I can confidently say that if the entire present Board were standing here next to me, they would endorse all I have said as underlying the importance the Board attaches to measures needed to ensure continuation of safety against inadvertent criticality.

Thank you for your presence and attention.